A MASS SPECTROMETER FOR USE IN THE STUDY OF SURFACE IONIZATION

BY
CLIFFORD RICHARD KEIZER
B.A., Hope College, 1939
M.S., University of Illinois, 1941

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
CHEMISTRY IN THE GRADUATE SCHOOL OF
THE UNIVERSITY OF ILLINOIS, 1943

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Introduction

When molecules strike a heated filament, a part or all of them may be ionized. The nature and the number of the ions formed may vary with the nature of the striking molecules, the kind of filament, its temperature, and the condition of its surface. Langmuir[1] has developed a theory relating these factors for the case of positive ions; Yonov[2] has developed a similar theory for negative ions.

A mass spectrometer is an instrument which by some combination of electric and magnetic fields separates ions with distinct values of the ratio of charge to mass (e/m) and permits determination of the relative numbers of each. There are four essential parts to the mass spectrometer: the ion source, the electric field, the magnetic field, and the recording device.

The mass spectrometer should give detailed information about the processes of surface ionization since it can be arranged to identify the different ions and to measure the number of each kind independently of the others. Recently such an instrument was built[3] based on the Bleakney[4] design. However, the results obtained were not satisfactory due to inhomogeneity in the electric field. Since the Bleakney design did not permit improvement of the homogeneity of the electric field, Epstein suggested the use of the Dempster[5] arrangement even though it suffers from the disadvantage of giving relative rather than absolute numbers of ions.

THEORY OF THE DEMPSTER TYPE MASS SPECTROMETER

The Dempster type mass spectrometer depends on the separation of ions by a homogeneous magnetic field after they have been uniformly accelerated in an electric field. The fundamental equation is

$$\frac{e}{m} = \frac{V c^2}{150 H^2 r^2},$$

where e is the charge on the ion in electrostatic units, m the mass of the ion in grams, V the accelerating potential in practical volts, c the velocity of light in centimeters per second, H the magnetic field intensity in oersteds, and r the radius of the ion in centimeters.

The theoretical resolution of such an instrument is given by

$$\frac{\triangle m}{m} = \frac{2 \triangle r}{r}.$$

The quantity $\triangle m$ represents the increment in m which can be detected. $\triangle r$ is given approximately by the average width of the slits through which the ions enter and leave the magnetic field. If r is assumed to be 4 centimeters, $\triangle r$ 0.5 millimeter, and $\triangle m$ unity, m is calculated to be 80; thus we may expect the instrument to separate an ion of mass 80 from an ion of mass 79. It is apparent that decreasing the slit width increases the resolving power. However, decreasing the slit width involves decreasing the intensity of the ion current.

THE MAGNETIC FIELD

Ference, Shaw, and Stephenson[6] have shown that by suitably varying the distance between a pair of equivalent coils mounted coaxially an annular region can be obtained in which the magnetic field is very uniform. As the distance between the coils increases the mean radius of this annulus decreases. To provide the magnetic field requisite for the mass spectrometer a pair of coils was designed and built. Each coil consisted of twelve "pancakes" of copper strip windings (0.5 x 6 mm.) insulated from adjacent windings with asbestos strip (0.3 x 6 mm.). These "pancakes" were separated by transite spacers (3 x 5 x 90 mm.) cemented in place with water glass. These spacers also provided a channel for air cooling. Each "pancake" had approximately 108 turns.

The radial variation of the magnetic field intensity at

several coil separations was studied with a magnetometer. The principle was that of balancing the magnetic field produced within the coils against a magnetic field in the opposite direction produced within a standard solenoid. By determining the ratio of current through the coils and standard solenoid at balance one could determine constants permitting the calculation of the magnetic field produced within the coils. The magnetometer was mounted in the median plane of the standard solenoid, which was provided with slides and an elevating mechanism by means of which these ratios of current could be taken at any desired point within the coils.

A separation was found for which the magnetic field was sufficiently constant over an annulus of the desired radius. The radial variation at each coil separation was found to be in agreement with the calculated variation within experimental error.

THE PROPOSED CELL

Designs are given for the other parts of the proposed mass spectrometer: a furnace with shields for producing a molecular beam; an ionizing filament with a plate and slit system for applying the accelerating potential and defining the ion beam; and a collecting filament with a shield. For amplifying the ion current the DuBridge and Brown[7] circuit employing the FP-54 Pliotron tube was shown by Epstein[3] to be satisfactory.

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VITA

The author was born March 19, 1918 near Hudsonville, Michigan. Soon thereafter Byron Center, Michigan became his home and he received his elementary education there. After graduating from Byron Center High School he entered Hope College in September, 1935 and received the degree of Bachelor of Arts cum laude in June, 1939. From September, 1939 to June, 1942 he was a teaching assistant in the Department of Chemistry at the University of Illinois while doing graduate work there. He received the degree of Master of Science in Chemistry in February, 1941. During the academic year 1942-43 he held a Graduate School Fellowship. He is a member of Phi Beta Kappa, Phi Kappa Phi, Phi Lambda Upsilon, and Sigma Xi.

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